Chemistry of Ultra-Faint Dwarf Galaxies in the Dark Energy Survey

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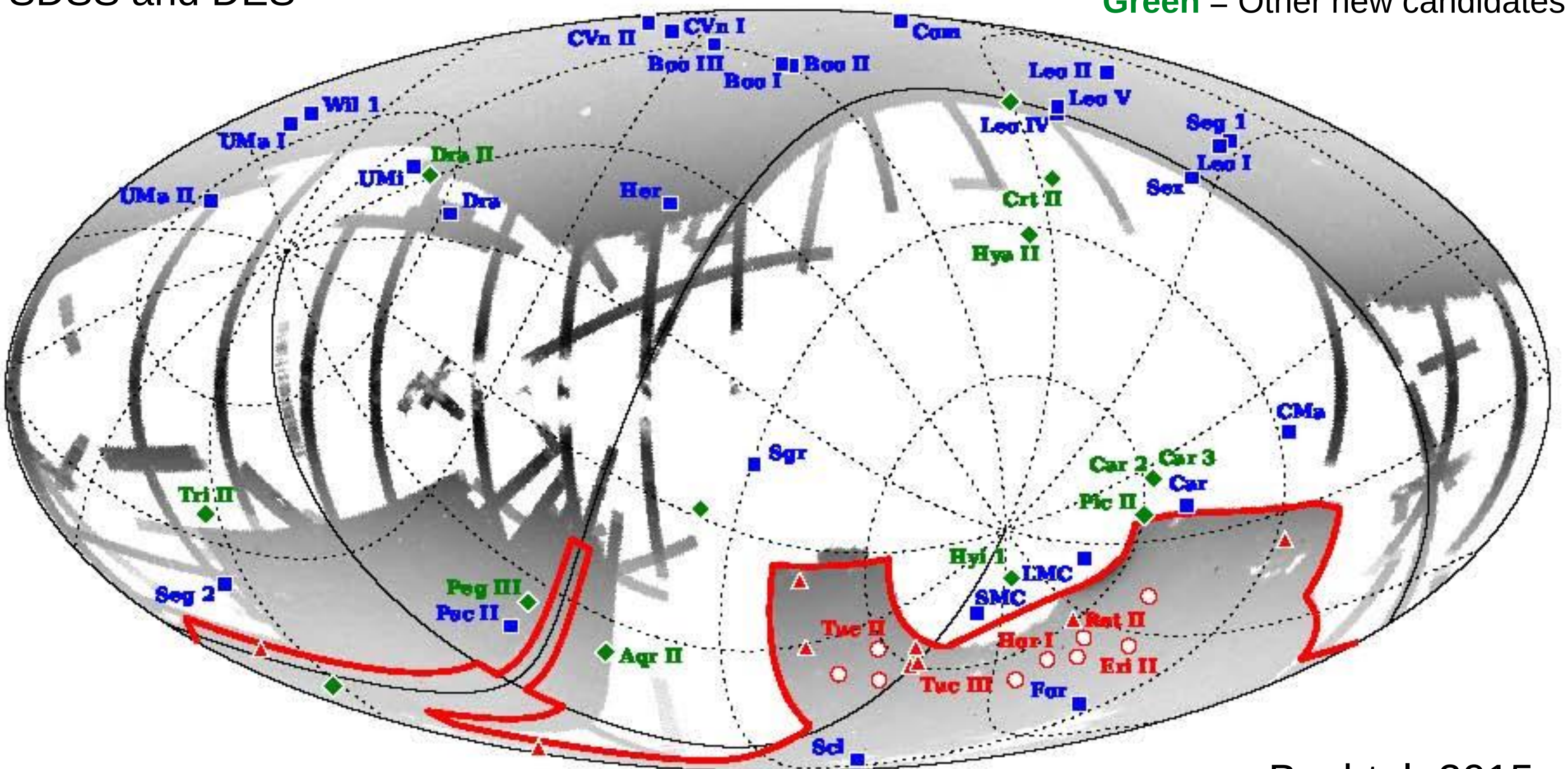
and the DES Milky Way Working Group

20+ satellites discovered by DES

Blue = Known prior to 2015
Red triangles = DES Y2Q1 candidates
Red circles = DES Y1A1 candidates
Green = Other new candidates

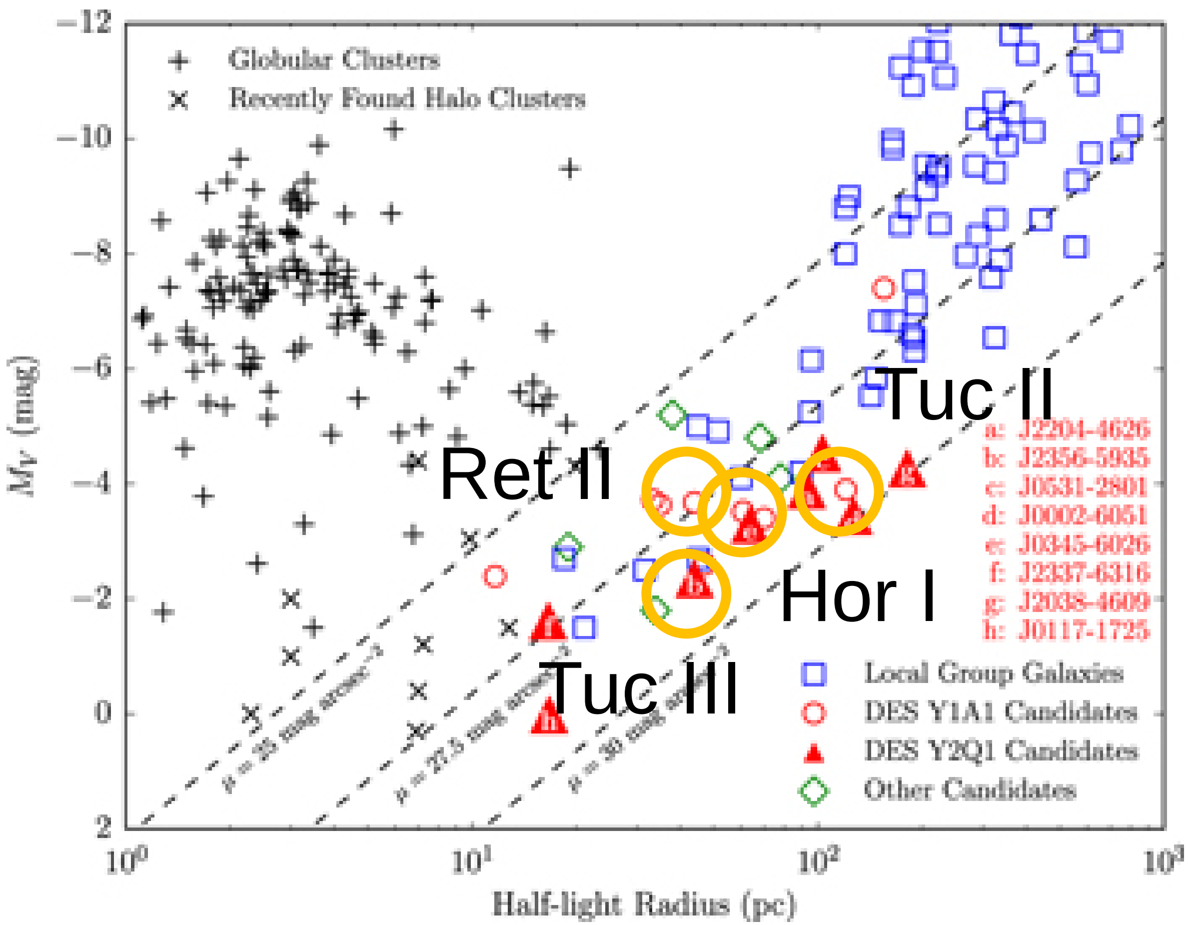
Stellar density field from SDSS and DES



DES footprint in Galactic coordinates (~5000 deg^2)

Bechtol+2015
Drlica-Wagner+2015

20+ satellites discovered by DES

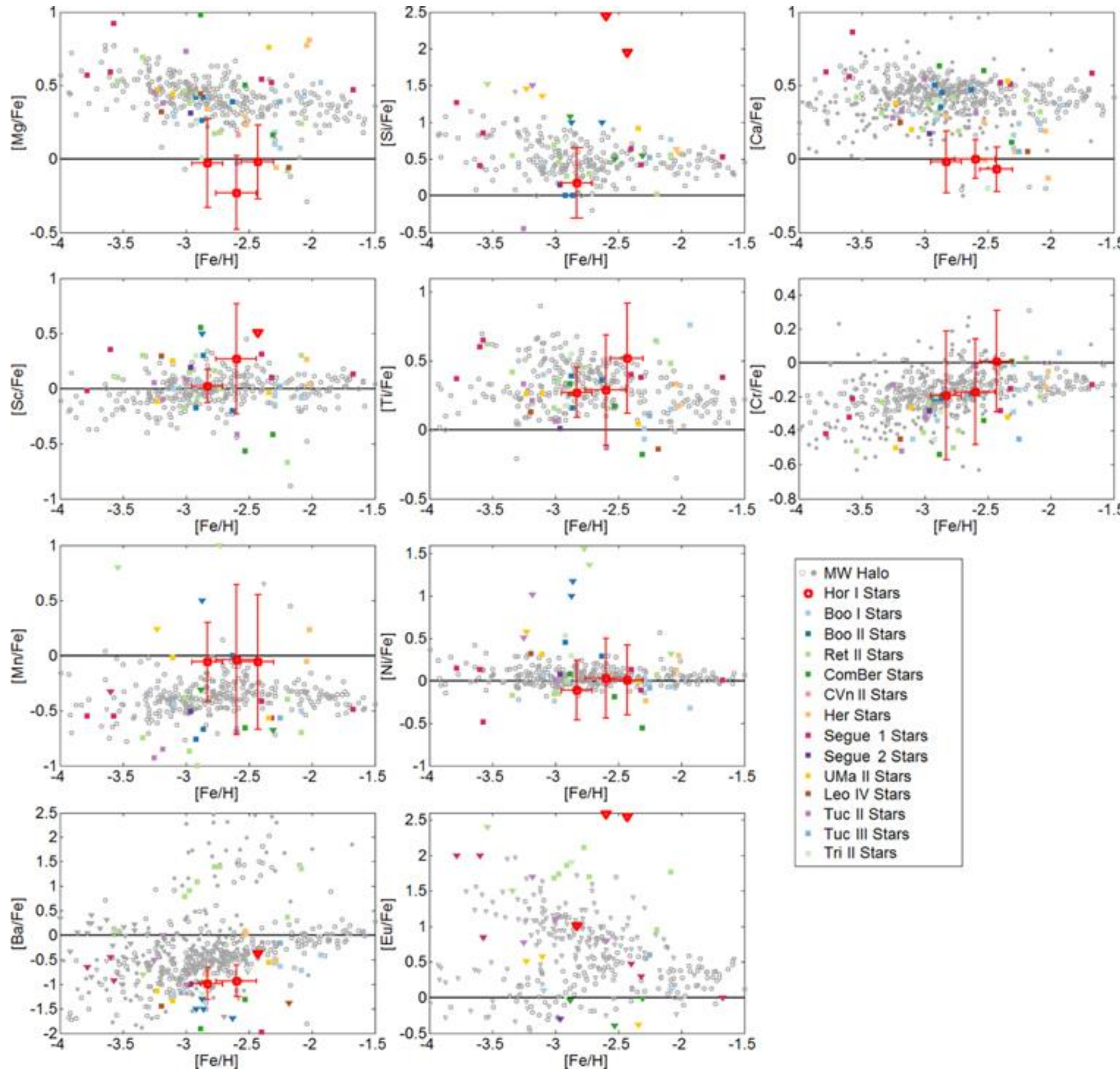


Drlica-Wagner+2015

- DES satellites have lower masses than previously-known dwarfs
- Potential for single nucleosynthetic event to influence all stars in galaxy
- Physical isolation (and reionization) preserves “fossil record” until today

Horologium I chemistry

- Hor I has solar-type abundances, very unusual for a metal-poor stellar population

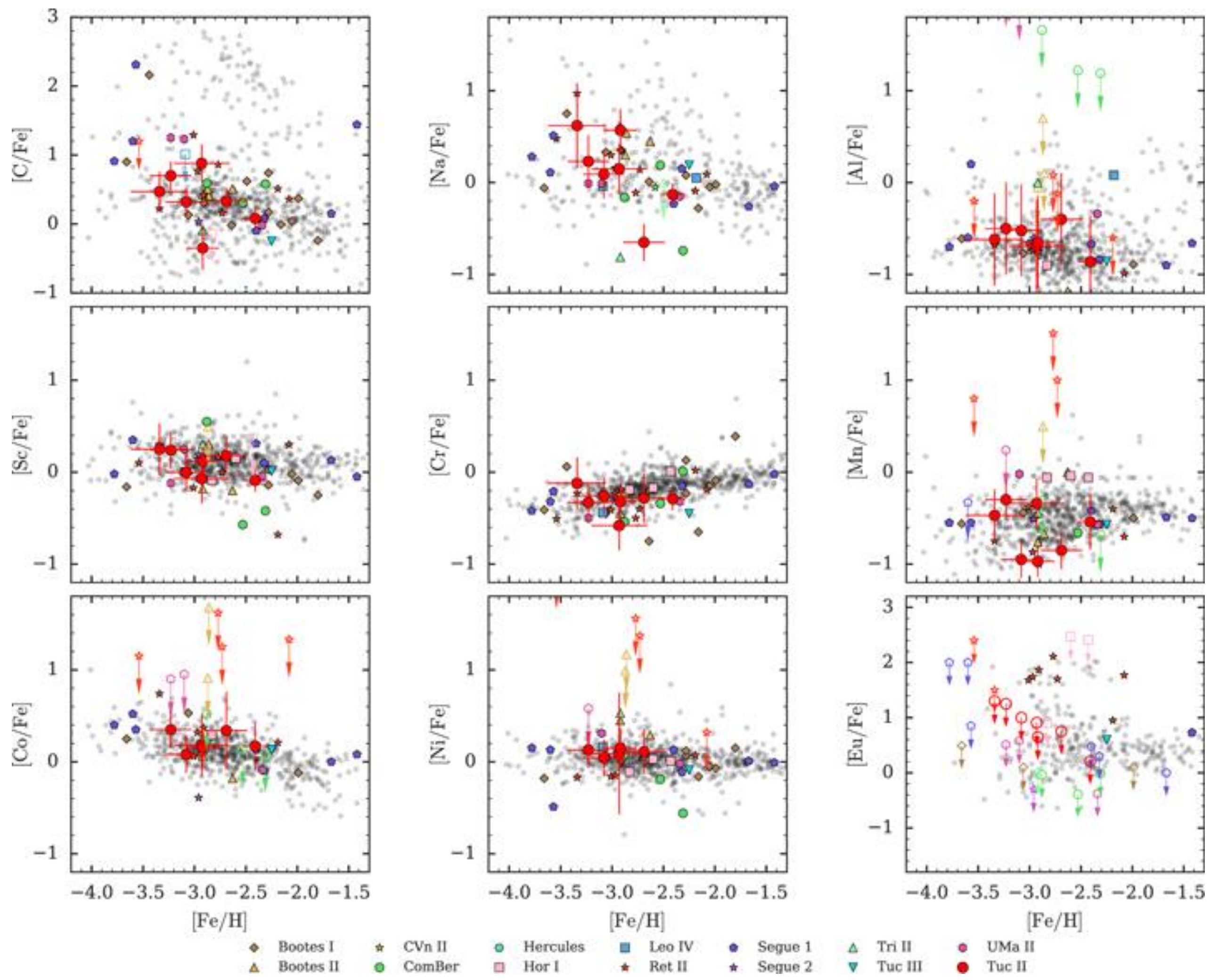


Red points: Hor I stars; colored points: stars in other UFDs; grey points: MW halo stars

Nagasawa+2018

Tucana II chemistry

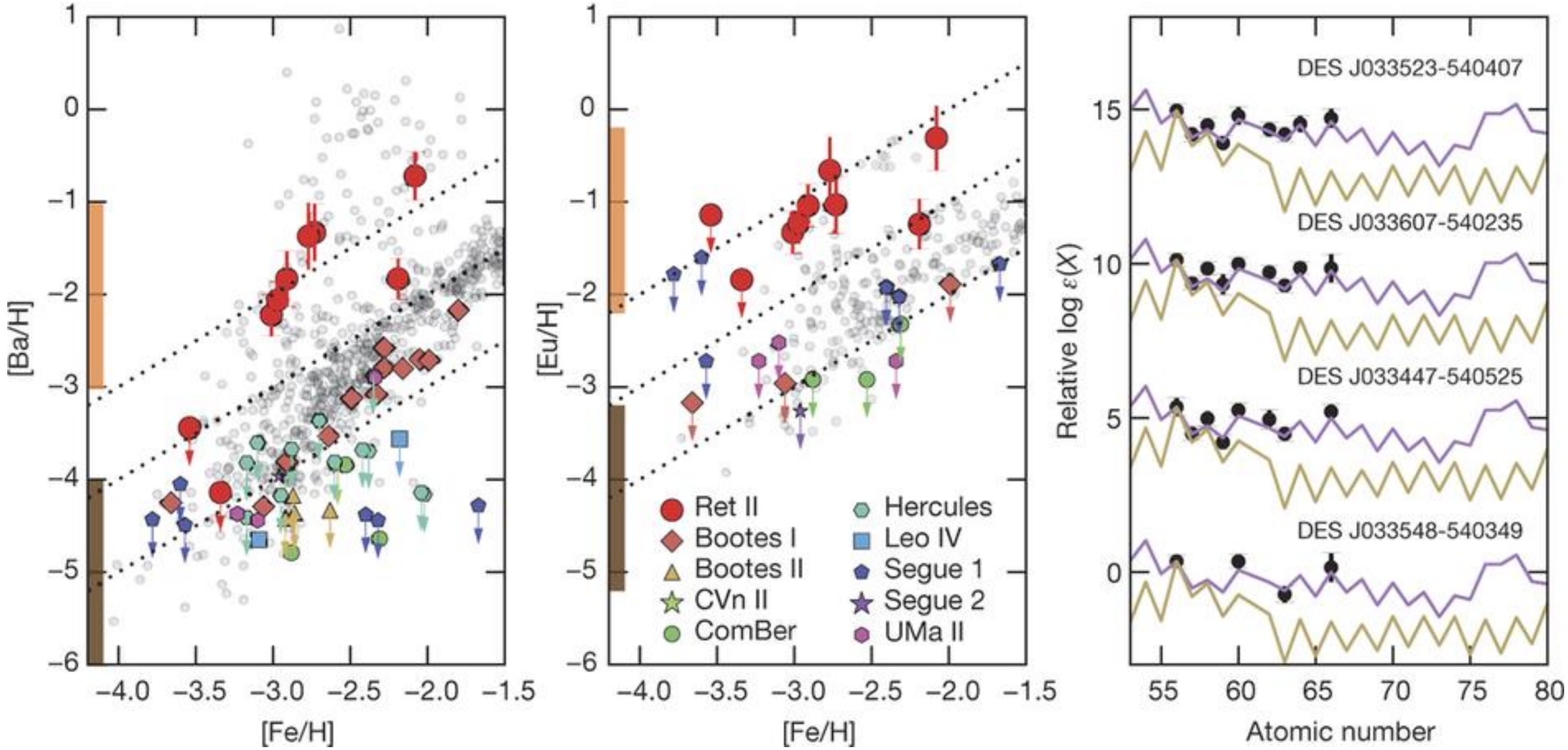
- Tuc II has chemical diversity
- May be a surviving "first galaxy"
  - But for one rogue star



Ji+2016a; Chiti+2018

Reticulum II chemistry

- Detailed chemical abundance patterns of stars in Ret II show high levels of rapid neutron-capture element enhancement (*r*-II)



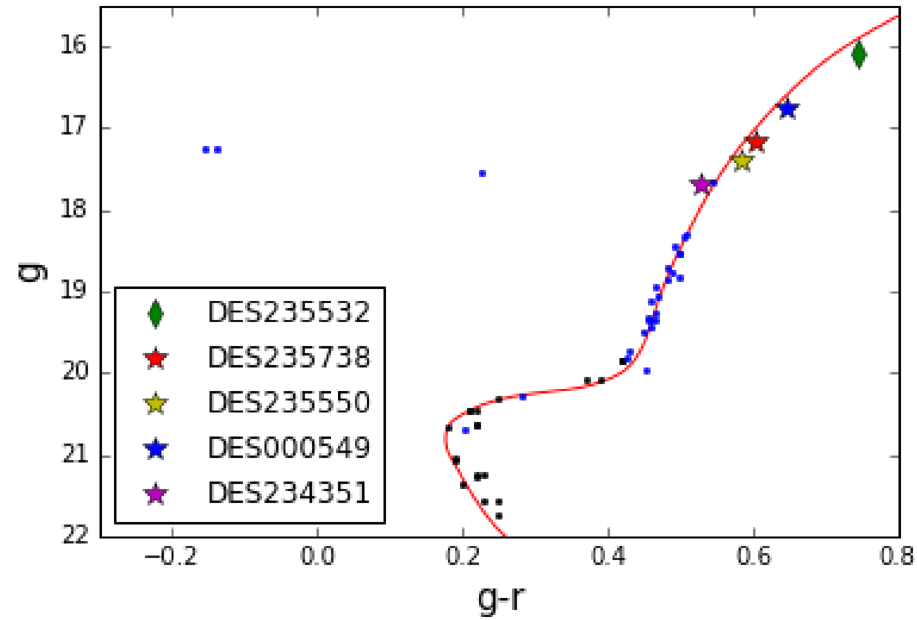
Ji+2016b; scaled solar *r*-process (purple) and *s*-process (yellow) patterns are shown

- Suggested explanation is a binary neutron star merger early in this small galaxy polluted the entire population of stars

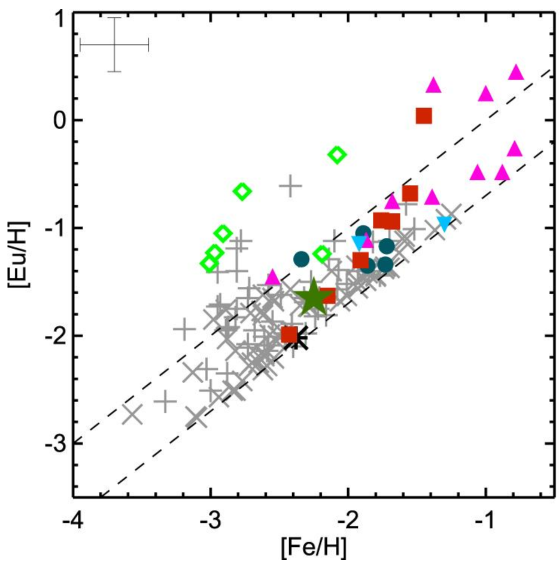
Tucana III chemistry

DARK ENERGY SURVEY

- Brightest star studied by Hansen+2017 shown to be mildly *r*-process enhanced (*r*-I)
- Four more stars observed in core+tails, Li+2018

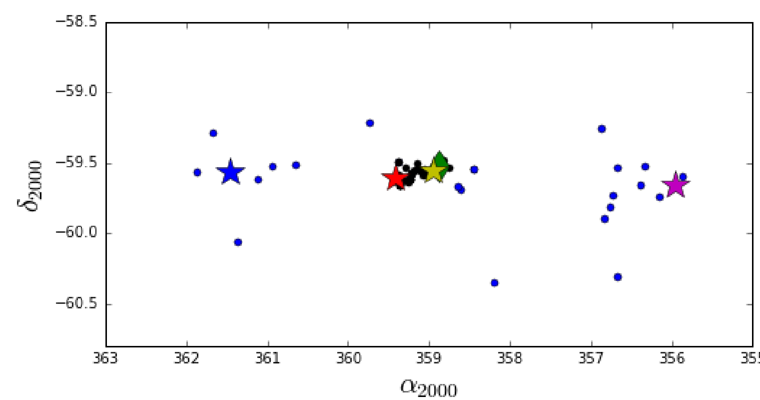


Marshall, Hansen+*in prep*



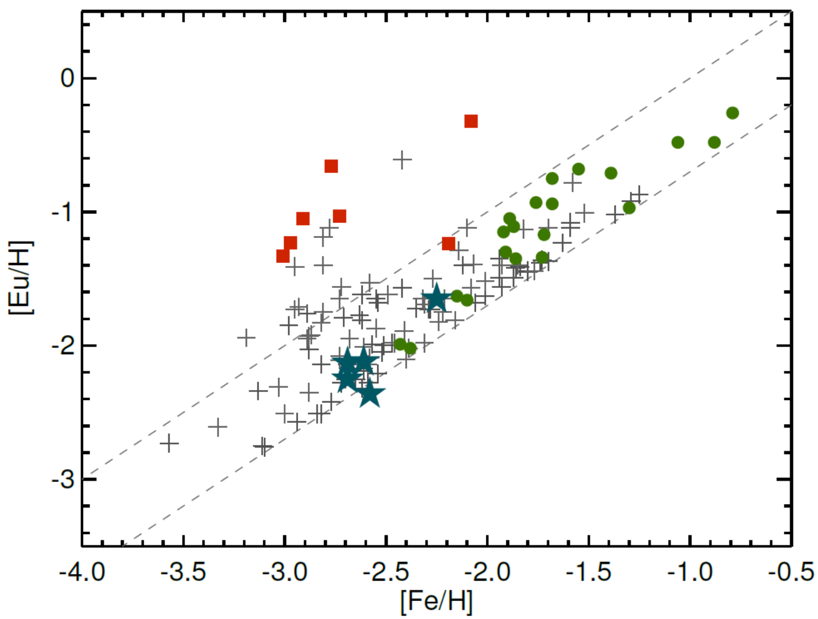
Hansen+2017

Grey lines define *r*-I stars; red squares are Ret-II stars



Tucana III chemistry

- All five stars in Tuc III are *r*-I stars
  - One star has some *s*-process as well



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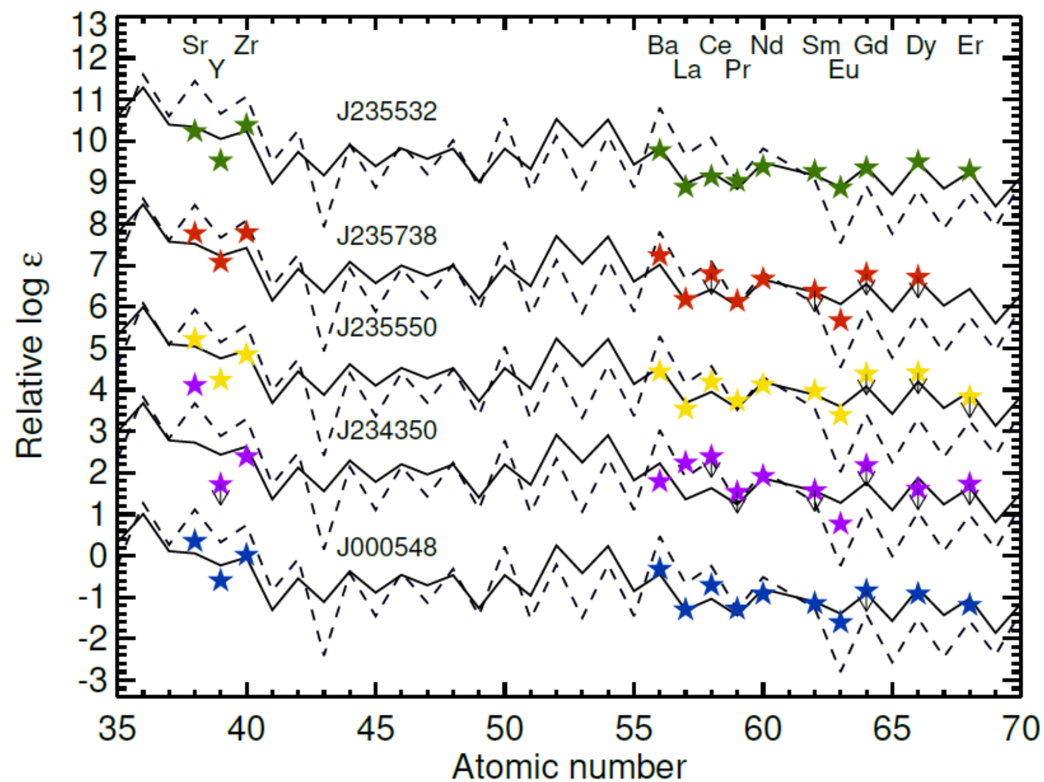
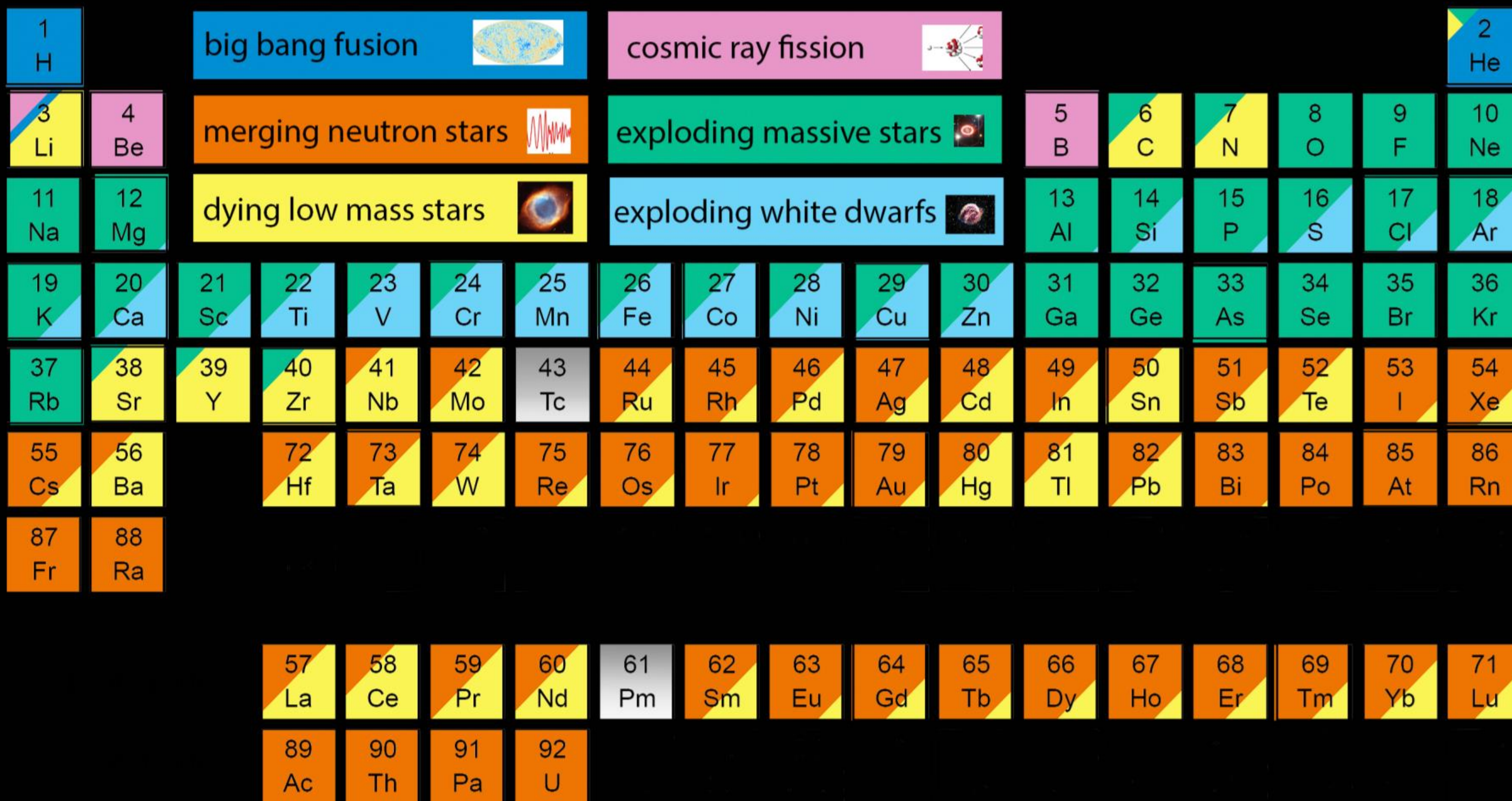


Solid: scaled solar *r*-process; dashed: scaled solar *s*-process

Marshall, Hansen+*in prep*

The Origin of the Solar System Elements



Graphic created by Jennifer Johnson

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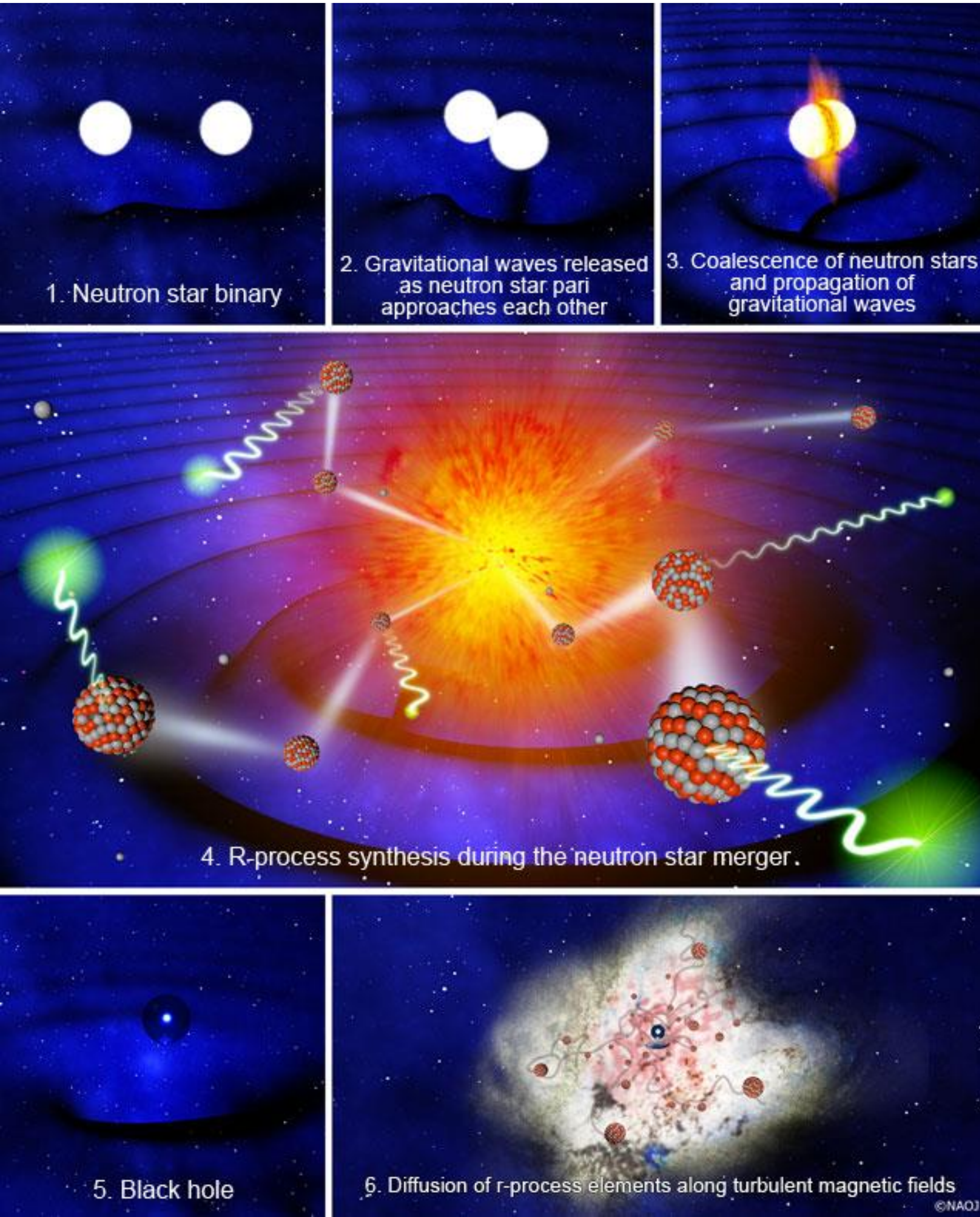
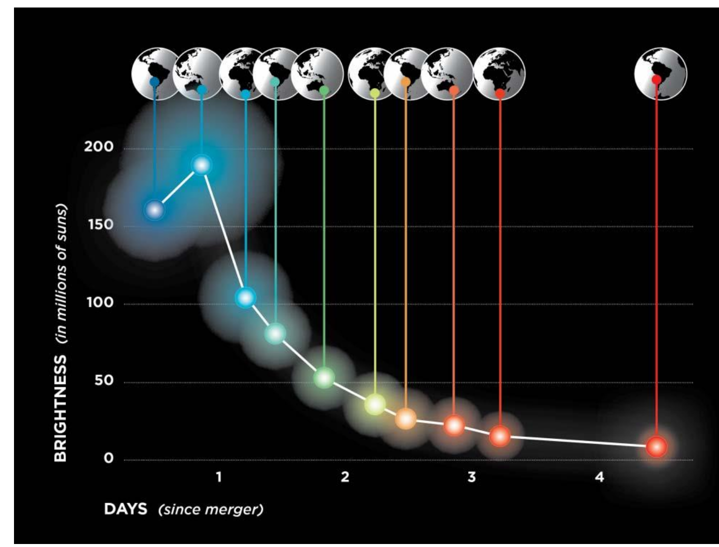


Cartoon of the theoretical phases of a binary neutron star merger event

Image credit: “Enrichment history of r-process elements shaped by a merger of neutron star pairs” Tsujimoto & Shigeyama 2014



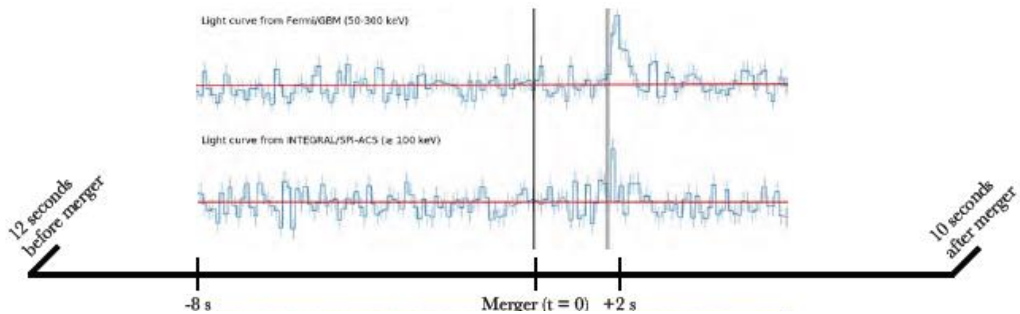
Theoretical models make specific predictions of how these events should evolve with time.

Image credit: Las Cumbres Observatory

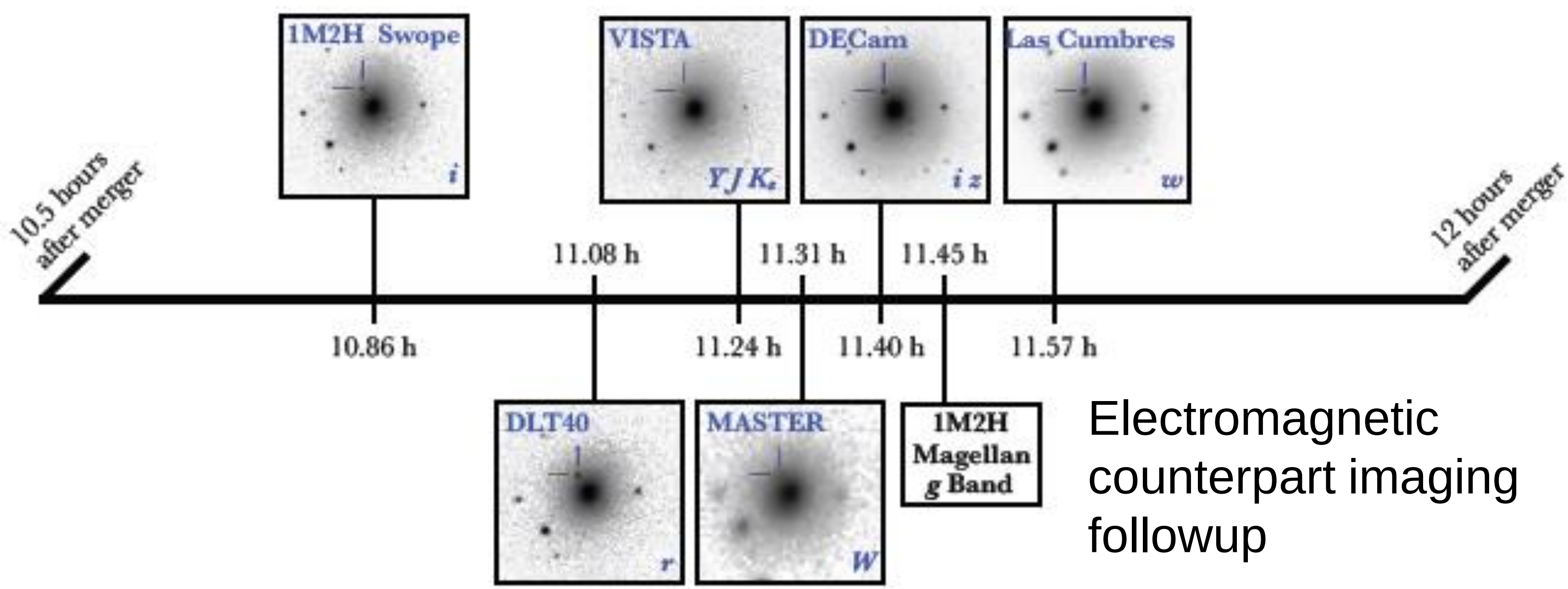
DARK ENERGY SURVEY

LIGO announces first GW signature of a binary NS merger

LIGO/VIRGO detection



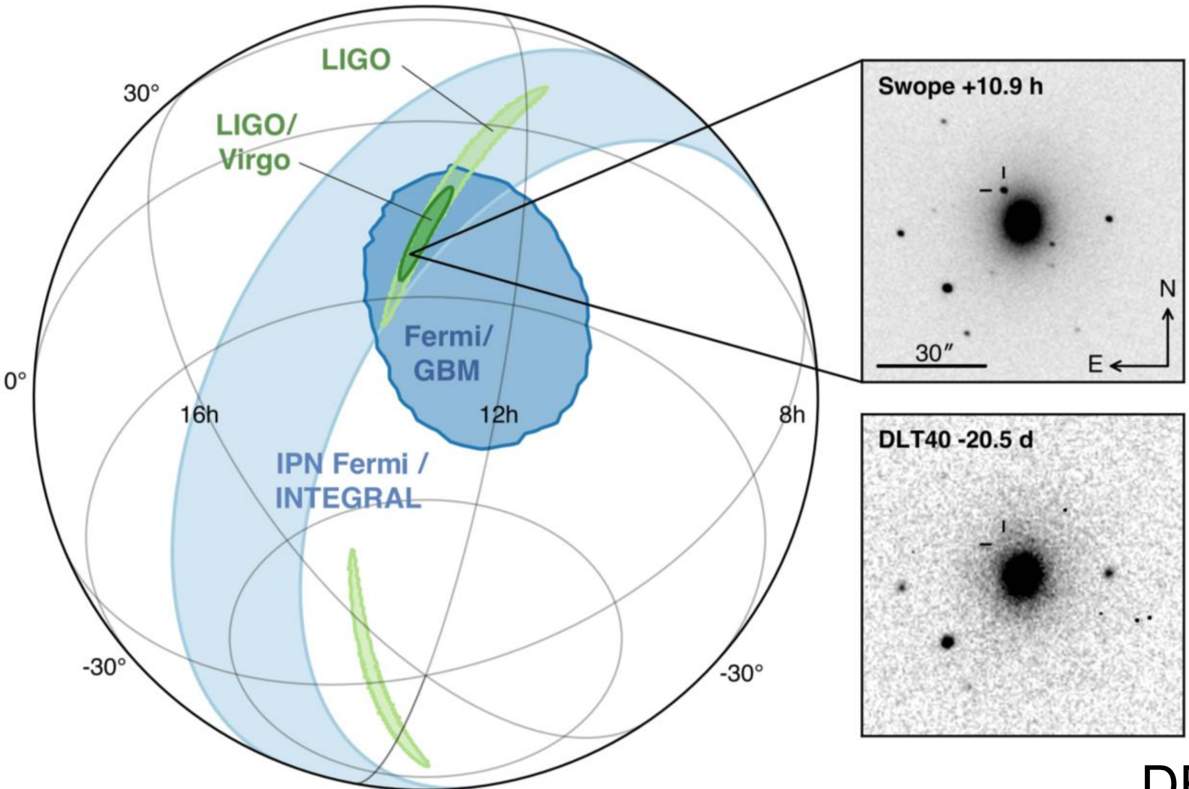
“Multi-messenger Observations of a Binary Neutron Star Merger”, LIGO scientific collaboration, VIRGO collaboration, and partner astronomy groups (including 3600+ authors!), 2017

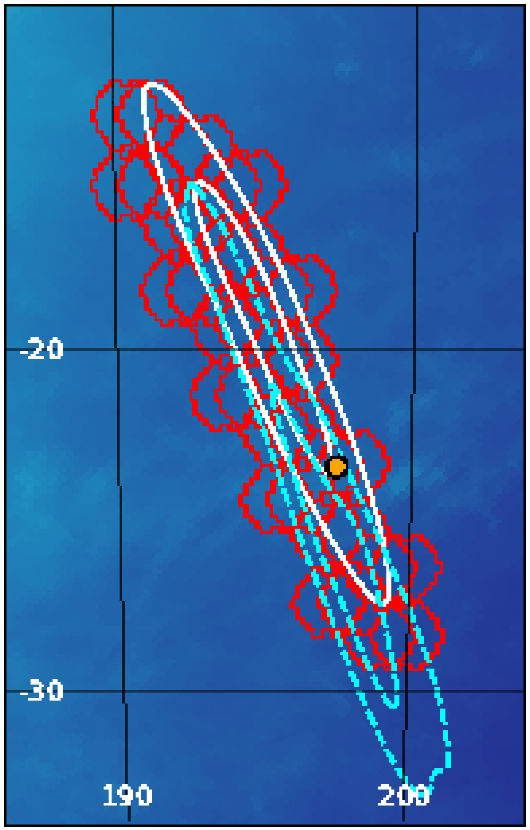


Electromagnetic counterpart imaging followup

DECam is a great instrument for LIGO followup

Even with Virgo, LIGO's localization of GW events was not very precise



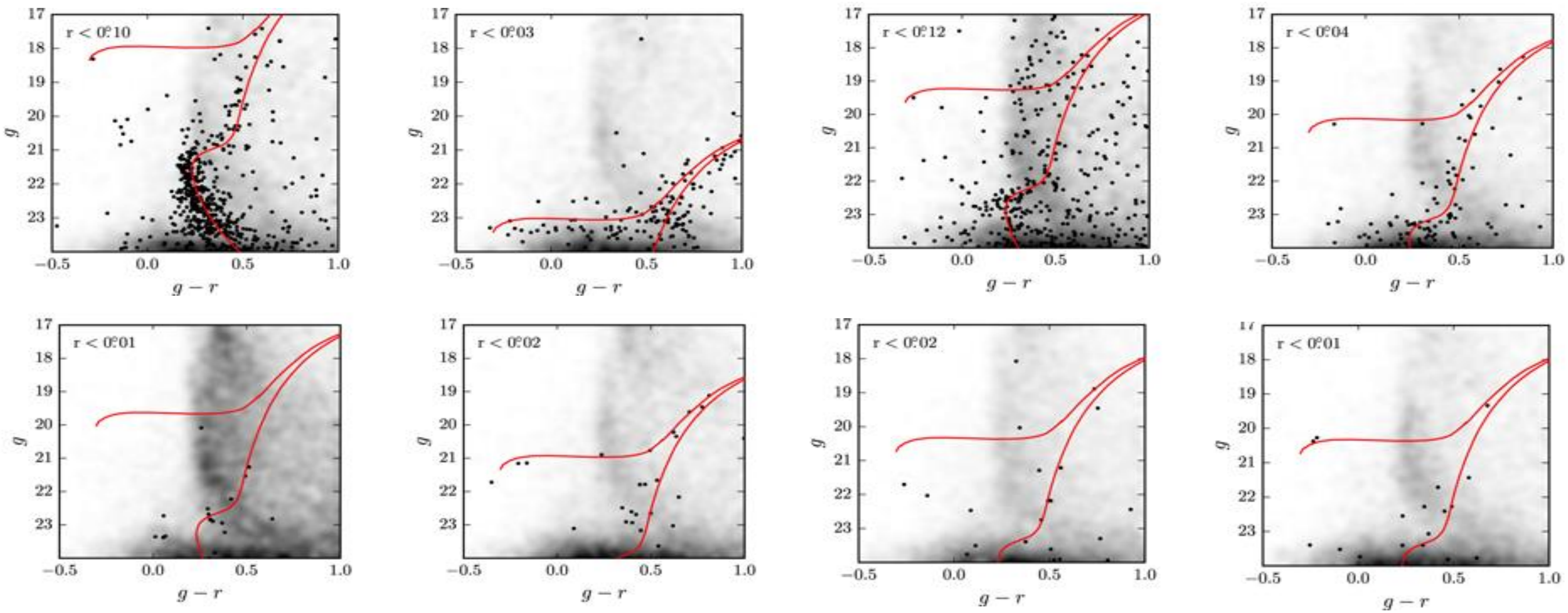


DECam's large FOV covered the region in only 10 pointings; Soares-Santos+2017

The future

- We will soon have observed every DES satellite star that can be studied at high resolution with today's telescopes

Ret II | Eri II | Tuc II | Hor I



Ind I | Pic I | Phe II | Eri III

DES Y1 candidates; Bechtol+2015

DARK ENERGY SURVEY

The future

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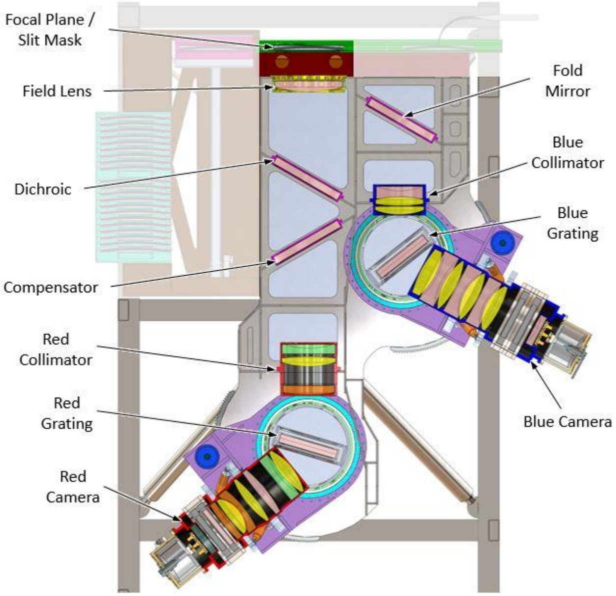
- LSST should find ~100 more ultra-faint dwarfs
  – But only after several years

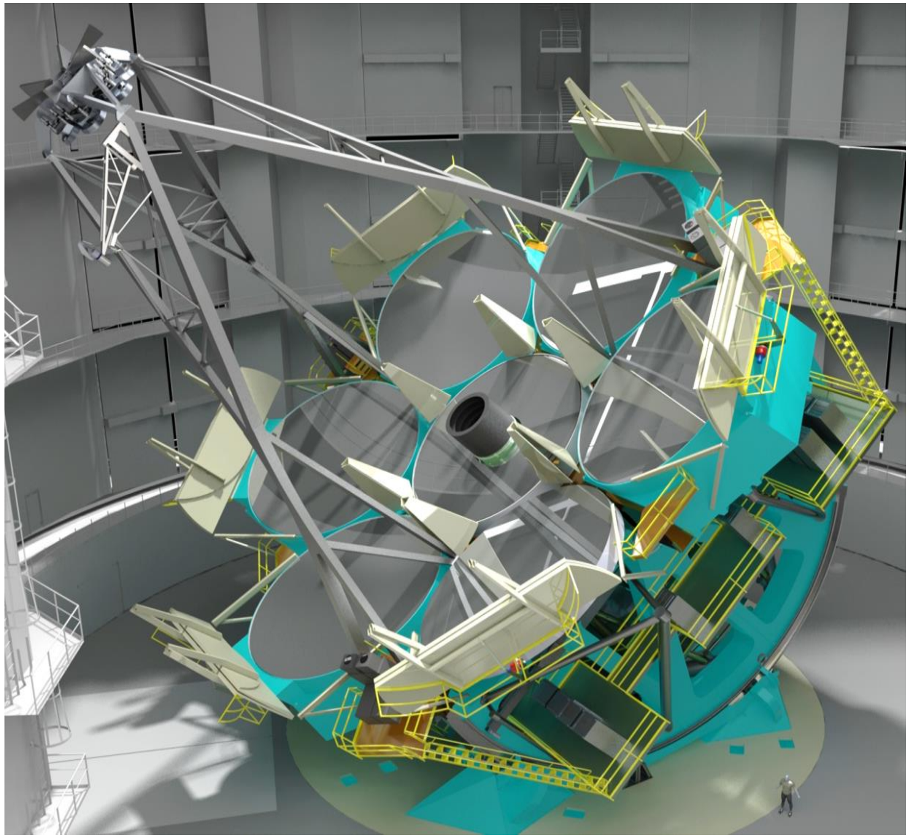
- Next generation telescopes will be essential in studying additional stars in the DES dwarfs as well as new objects discovered by LSST and others

GMT first light instruments

DARK ENERGY SURVEY

GMACS: the wide-field, moderate resolution multiobject spectrograph





The Giant Magellan Telescope

G-CLEF: an extreme precision radial velocity spectrograph

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- By studying chemistry of satellites and halo stars, we will likely know the production sites of all elements on the Periodic Table in the next few years